A Simple and Cheap Technique for Better Positioning Under Bad Environment : GPS Buffering Algorithm

Chang-Wan Jeon*, Kwan-Sun Choi*, Dong-Sik Kim*,Myoung-Koo Kim*, Yu-Mi Lee*
Sangyeon Woo**

* Dept. of Electrical and Communication System Engineering, Soonchunhyang University, Asan, Korea (Tel : +82-41-530-1372)
** Division of Physical Education

Abstract: - In these days, many Personal Digital Assistant (PDA) products equipped with GPS receiver for PNS (Personal Navigation System) are on the market. Furthermore many robots will be equipped GPS receiver to navigate by itself in recent future. A common feature of PNS and robot navigation is slow moving, which often results in incorrect navigation. Besides slow moving case, surrounding environment which might block and reflect signals from satellites can degrade navigation accuracy. New and expensive GPS receiver, of course, can cope with the circumstance with additional S/W and/or H/W. Commonly used GPS receiver, however, undergoes navigation performance degradation in slow moving environment. In this paper, a new technique called GPS Buffering Algorithm (GBA) is proposed to improve navigation performance even in slow moving cases. Main idea of the GBA is to pre-process the output signals from a GPS receiver. The GBA analyzes, classifies, and filters the output signals based on moving dynamics. The GBA is a very economical method because it does not require additional H/W to improve navigation performance. Extensive GPS data are collected and tested to validate the GBA. Various test results are shown to verify the usefulness of the algorithm.

Keywords: - GPS, GBA, Algorithm, Navigation, Positioning

1 Introduction

Rapid development of IT area leads to increasing use of the PDA. In these days, many PDA products equipped with GPS receiver for PNS(Personal Navigation System) are on the market. Furthermore many robots will be equipped GPS receiver to navigate by itself in recent future. A common feature of PNS and robot navigation is slow moving, which often results in incorrect navigation. Besides slow moving case, surrounding environment which might block and reflect signals from satellites can degrade navigation accuracy. There are many kinds of GPS receivers. Some receivers are very expensive and give accurate navigation results even in poor environment. On the other hand, many GPS receivers are manufactured under cost consideration and can not cope with the poor environment properly. Using the commonly used receivers, it is not rare to experience navigation performance degradation such as position jumping and indeterminate heading angle because of changing continuously even when a vehicle stops[1-2]. In this paper, a new technique called GBA is proposed to improve navigation performance even in the above mentioned circumstance. Main idea of the algorithm is to pre-process the output signals from a GPS receiver instead of directly using it for navigation.

2 Analysis of a typical GPS data

A navigation system using GPS can be equipped with a vehicle, PDA(Personal Data Assistant), robot, and so on under various environments such as driving, hiking, mountain-climbing and walking. Therefore GPS data for two cases, that is, driving and walking, are analyzed.

2.1 Driving case

The figure 1 shows typical feature of GPS data while driving downtown.

Part (a) and (d) are the starting point and the ending point of the trajectory, respectively. The magnified figures of four areas in figure 1 are shown in figure 2. Part (a), (c), and (d) correspond to slow moving(or stopping) case. As shown in the figure, positioning ability is not good in those cases. On the other hand position jumping phenomenon is shown in (b), which means GPS signals are blocked because of environment. Therefore it may be helpful if a pre-process algorithm to enhance positioning accuracy in those cases is developed.

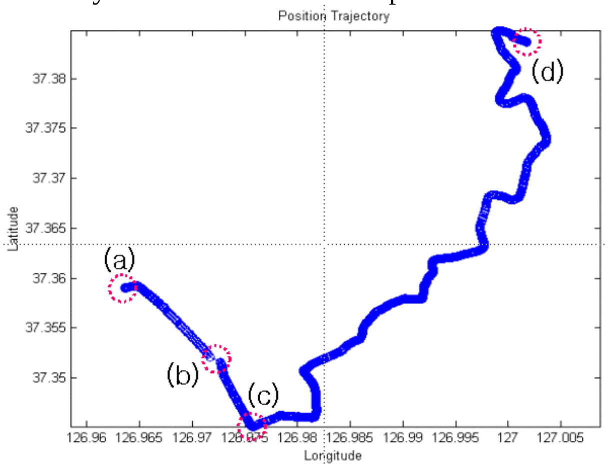


Fig. 1 Feature of the trajectory while driving.

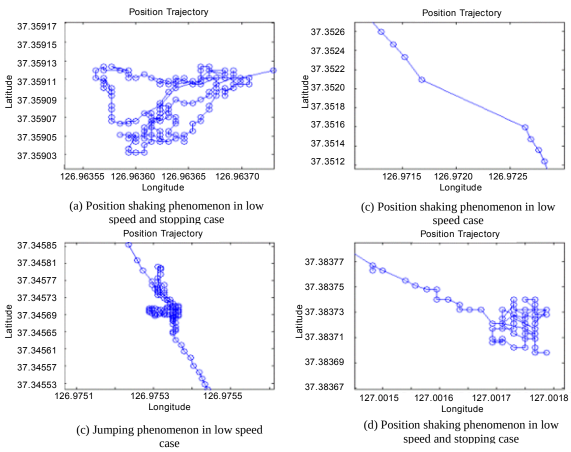


Fig. 2 Magnified figures of four areas in figure 1

.

Figure 3 shows the relationship between DOP and number of satellites while driving. As shown in the figure, DOP increases more than 3 while number of receiving satellites increases. Figure 4 shows the relationship between heading angle and velocity while driving. (a) and (b) are undesirable peaks of velocity. In case of velocity less than 10km/h, we can see that heading angle is shaken randomly. If we can correct the heading angle, we can obtain more accurate position.

2.2 Walking case

The figure 4 shows typical feature of GPS data while walking.

Part (a) and (d) are the starting point and the ending point of the trajectory, respectively. The magnified figures of four areas in figure 5 are shown in figure 6. Part (a), (b), (c), and (d) correspond to slow moving(or stopping) case. As shown in the figure, positioning ability is not good as in the case of driving.

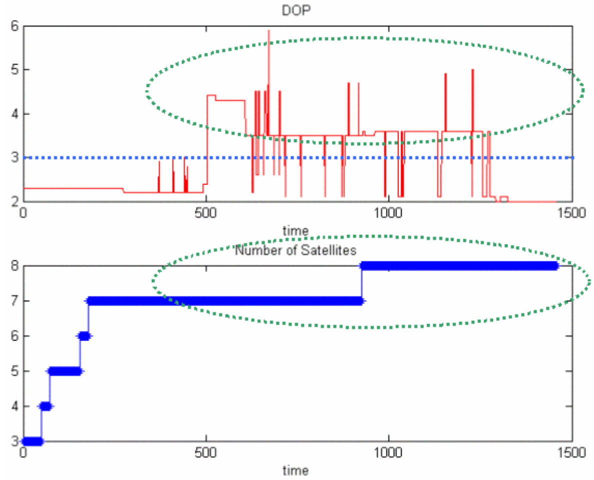


Fig. 3. DOP vs. number of satellites while driving.

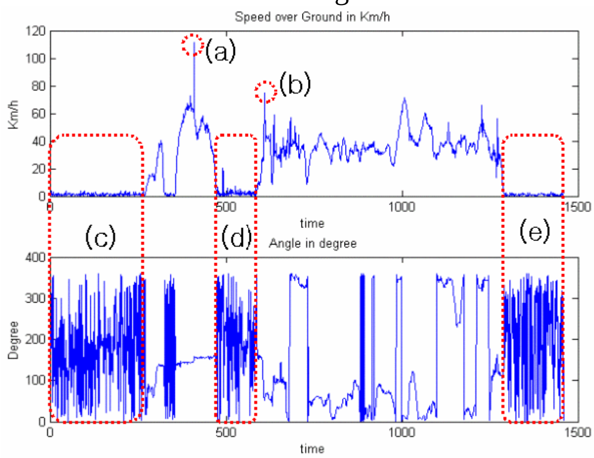


Fig. 4. Heading angle vs. velocity while driving.

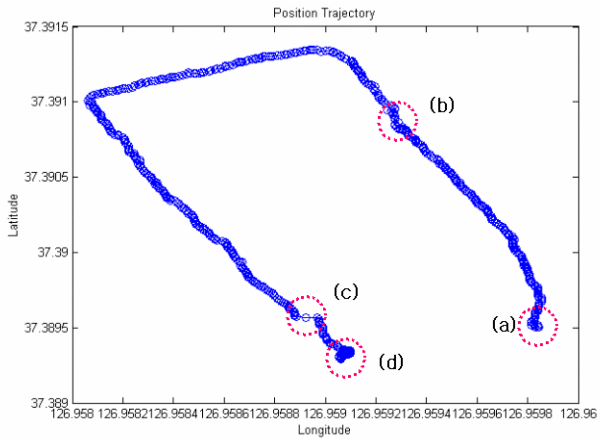


Fig. 5 Feature of the trajectory while walking.

Figure 7 shows the relationship between DOP and number of satellites while walking. The same analysis can be applied to the case. Figure 8 shows the relationship between heading angle and velocity while walking. We can see the same tendency as in the driving case.

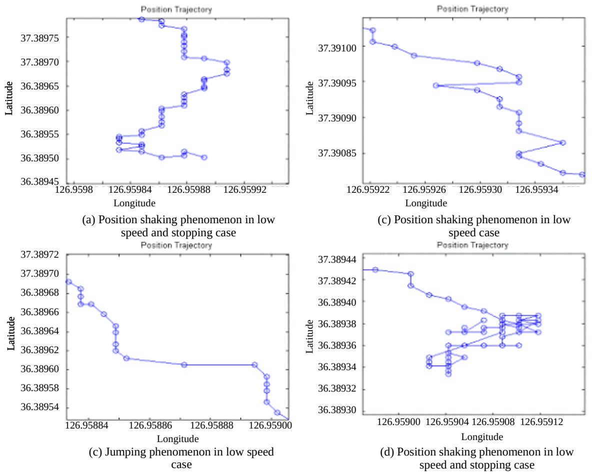


Fig. 6 Magnified figures of four areas in figure 4.

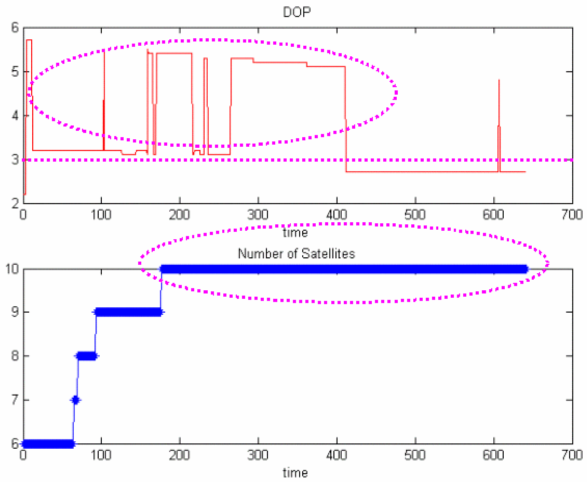


Fig. 7 DOP vs. number of satellites while walking.

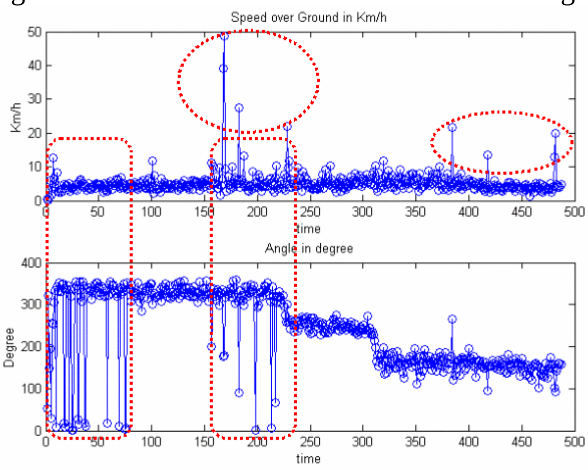


Fig. 8 Heading angle vs. velocity while walking.

3 Development of GBA

Based on the above analysis, the GBA algorithm is developed in this chapter. Main idea of the algorithm is to process the received GPS data before using them to calculate position. The algorithm is composed of several parts shown in Fig.9. One feature of the algorithm is that it does not depend on special format (for example, NMEA format).

In Check Data Synchronization (CDS) part, analyze header of the received data and compare it with the data obtained before. Based on the comparison results, recognize what protocol is used and analyze the contained information such as user present time, longitude, latitude, height, velocity, heading angle, DOP, available number of satellites, satellite identification number, azimuth, angle of elevation, and SNR. Then check if the data receives normally and if it is synchronized or not. Finally, determine whether we adopt the data or discard it based on the checked results

In Decide Data Level (DDL) part, classify the data from CDS by velocity using pre-determined threshold. Also in DDL, determine which satellites will be used for positioning and which satellites will be taken precedence for positioning based on received information in CDS and some analysis results.

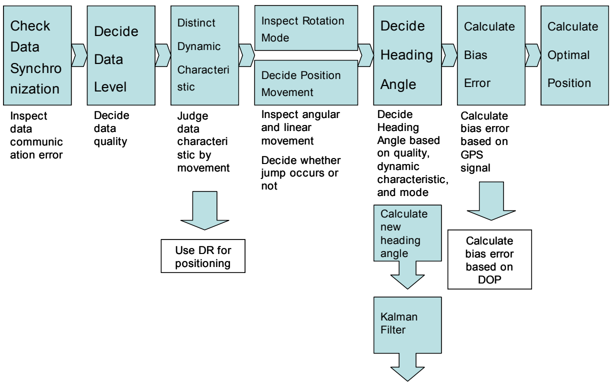


Figure .9 Flow diagram of the algorithm

In Distinct Dynamic Characteristic (DDC) part, firstly, determine if the designated position and heading angle from GPS receiver will be accepted or not using dynamics of moving object and some information from DDL such as data level, satellite usage priority, velocity, heading angle, statistical trend of position, and pre-determined threshold. To distinct position data, presume present position using a moving pattern from dynamic characteristic and DR (Dead Reckon) as below.

$$x_k = x_{k-1} + r_k \cdot \sin\theta_k \quad (1)$$

$$y_k = y_{k-1} + r_k \cdot \cos\theta_k \quad (2)$$

$$\theta_k = \theta_{k-1} + \Delta\theta_k \quad (3)$$

$$r_k = v_{k-1} \cdot (t_{k-1} - t_k) \quad (4)$$

where x_k and y_k are two dimensional position coordinate in time interval $[k-1,k]$, r_k is moving distance in time interval $[k-1,k]$, θ_k is attitude angle of moving object in time interval $[k-1,k]$, and v_k is velocity at time k. Then, determine if we accept the position data from GPS receiver or not using the presumed DR position. Like this, we can eliminate position errors which might be contained due to multi-path. Figure 10 shows dynamic characteristic of a vehicle while driving. Position rate means distance (present position – previous position) divided by time interval (1 sec in the paper). From the figure, it can be explained why the idea mentioned above is reasonable. In the figure, dynamic characteristic is classified as four cases.

As shown in the figure, CASE 1 corresponds to the case position rate > velocity while CASE 2 is the reverse case. CASE 3, no position change even though velocity exists, is a case with suspicious reliability. CASE 4 is reverse case of CASE 3. Slope =1 is the ideal case when time interval is 1 sec. From the above analysis, the GBA corrects some position data located outside the pre-determined threshold.

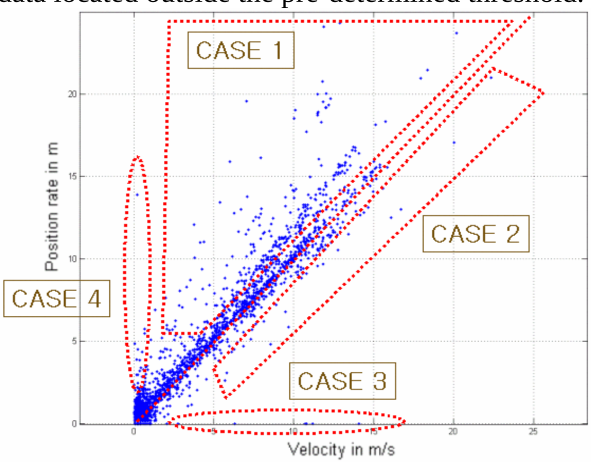


Fig. 10 Dynamic characteristic : velocity vs. position rate while driving

To distinct heading angle data, relationship of velocity and angular rate is depicted in figure 11. The figure is important because velocity and direction are closely related and they have great effect on positioning. Generally speaking, velocity might increase when a vehicle moves linearly(inside of the center strip in the figure) while velocity might decrease when a vehicle make a slow turning(below the dotted line in the figure). Therefore the data inside of the dotted circle might be abnormal. In this paper, 20 km/h and ±50° are determined as velocity and heading angle threshold, respectively. In other words, GBA corrects the received data when they are located in the dotted circle in the figure.

Information from DDC passes on the Inspect Rotation Mode (IRM) and Decide Position Movement (DPM). In IRM, inspect heading angle well matched with the dynamics based on velocity information eliminated abnormal data. In DPM, check abnormality and well-matched dynamics on the position data from DDC and determine position movement if there is no abnormality and displacement matches the dynamics characteristic.

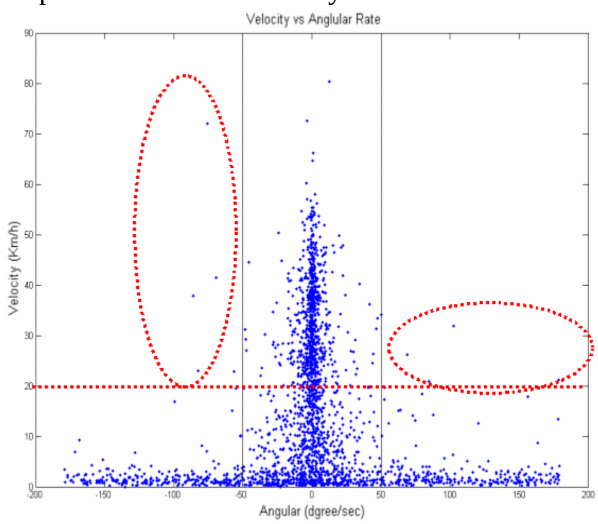
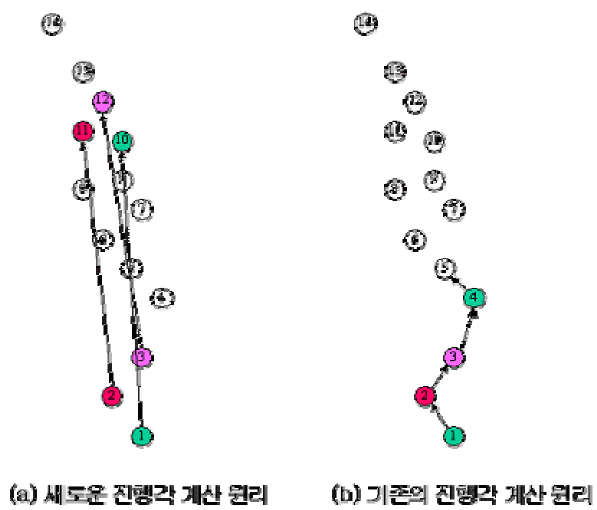


Fig. 11 Dynamic characteristic : velocity vs. angular rate while driving.



(a) New heading angle calculation principle **(b) Existing heading angle calculation principle**

Fig. 12 Concept of heading angle calculation

In Decide Heading Angle (DHA), determine heading angle based on the information from IRM and DPM. Because heading angle usually has large error when a vehicle stops or moves slowly, a new technique is devised as shown in figure 12. The new technique uses more than 10 data and calculates heading angle between 1st and 10th position at first. Next, calculate between 2nd and 11th position. By the same way, calculate consecutively to "between 9th and 18th position". The technique can give more correct heading angle when stop or slowly moving while it takes more time to set initial heading angle.

In Calculate Bias Error (CBE), calculate drift error and validate it using the elevation angle, azimuth, SNR, and DOP. Then position coordinate is corrected based on them. For this, the follow Kalman filter for heading angle and velocity is used.

• Kalman filter for heading angle[3]

When same magnitude of error appears in heading angle every sampling time, it is regarded as bias. Heading angle drift means inclination to one direction when it does not in real. This phenomenon is often appeared in gyroscope, but we take precaution against the case in GPS with the Kalman filter.

Eq. 5 and eq. 6 is process and measurement equation, respectively.

$$\begin{bmatrix}\delta\theta_{k+1}\\ \delta B_{k+1}\end{bmatrix}=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}\delta\theta_{k}\\ \delta B_{k}\end{bmatrix}+\begin{bmatrix}w_1\\ w_2\end{bmatrix}\begin{cases}w_k \sim N(0,Q_k)\\ x_0 \sim N(\hat{x}_0,P_0)\end{cases} \quad (6)$$

• Kalman filter for velocity

Velocity increment is estimated by the velocity Kalman filter. Eq. 9 and eq. 10 is process and measurement equation, respectively.

$$\delta x_{k+1}=\delta x_k + w_k,\ \begin{cases}w_k \sim N(0,Q_k)\\ x_0 \sim N(\hat{x}_0,P_0)\end{cases} \quad (9)$$

$$z_k=\delta x_k + v_k \quad v_k \sim N(0,R_k)\,. \quad (10)$$

In Calculate Optimal Position (COP), the final corrected position is determined based on data level, dynamic characteristic, corrected heading angle, movement, drift, and bias from the previous parts.

4 Application to real data

The developed GBA is applied to the data gathered by real world driving and walking which is already used chapter 2 for analysis.

The following figure 13 shows the filtered heading angle while driving. As shown in the figure, randomly shaking heading angle is disappeared when speed is low (a). (b) and (c) are the cases using previous velocity and heading angle because GPS signal is blocked by environment.

Figure 14 shows the filtered heading angle while walking. The GBA is more effective in PNS (Personal Navigation System) because 'walking' always means low speed.

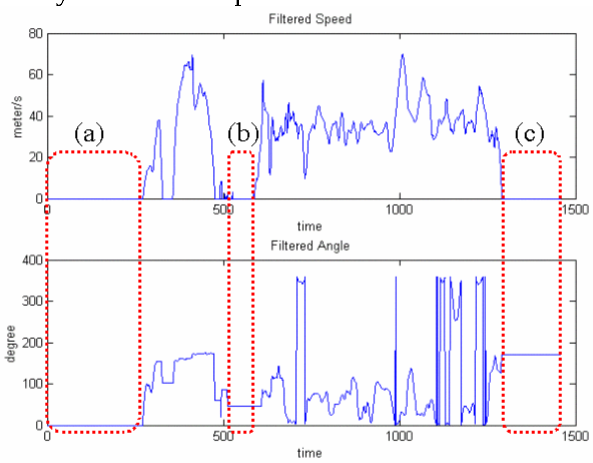


Fig. 13 Filtered velocity and heading angle while driving.

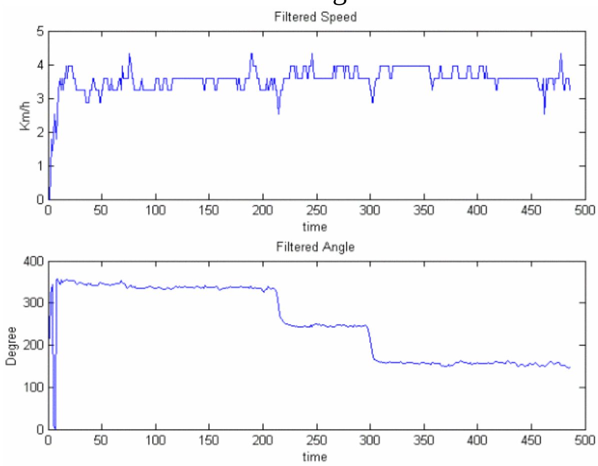


Fig. 14 Filtered velocity and heading angle while walking.

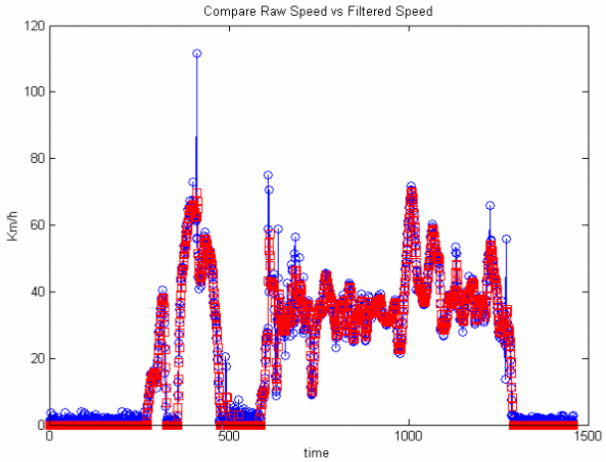


Fig. 15 Corrected vs. uncorrected velocity while driving

Figure 15 shows relationship between raw speed and corrected speed. □ and ○ denote corrected and raw speed, respectively. As shown the figure, peak values are diminished very much.

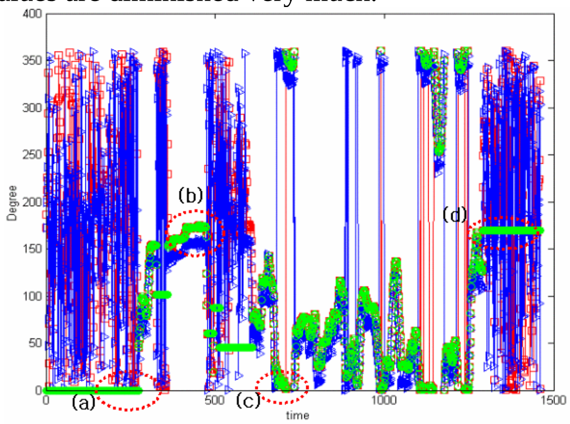


Fig. 16 Corrected vs. uncorrected heading angle while driving

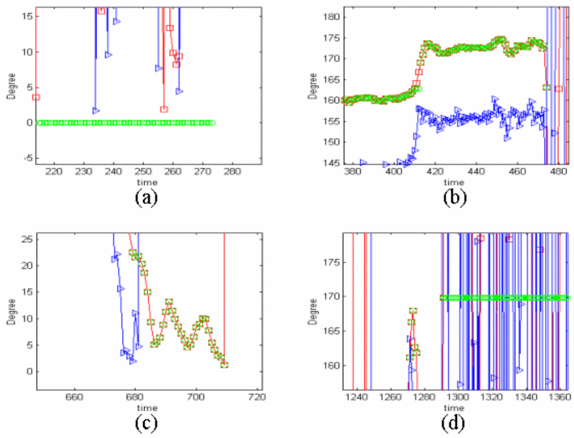


Fig. 17 Magnified figures of four areas in figure 16.

Figure 16 shows corrected (before and after Kalman filterin) and uncorrected heading angle. □ is uncorrected heading angle, □ is heading angle before filtering, and ○ is heading angle after filtering. Figure 17 shows magnified figures of four areas in figure 16. As shown in the figures, undesirable phenomenon was eliminated.

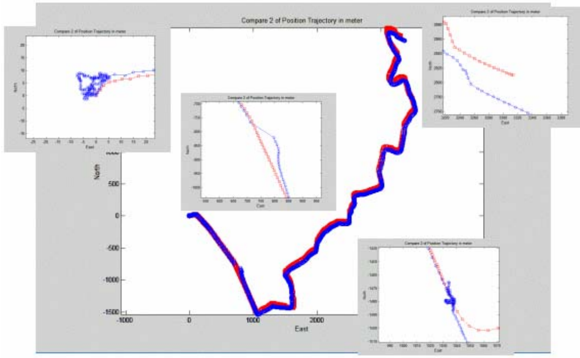


Fig. 18 Comparison corrected and uncorrected trajectories while driving

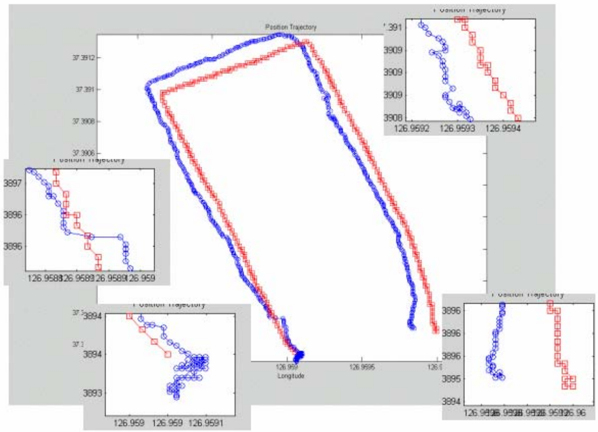


Fig. 19 Comparison corrected and uncorrected trajectories while walking

Figure 18 and 19 show trajectory comparison results between before and after algorithm application while driving and walking, respectively.

5 Conclusions

In this paper, a new algorithm named GBA is proposed for more correct positioning. The algorithm can be applied any GPS receiver because it uses only final GPS receiver output. For more improvement, it adopt Kalman filter for velocity and heading angle. As a result, we can obtain more correct position without any additional hardware which may raise cost. If newly developed RAIM technique[4-5] is applied to GBA, better results are expected.

References:

[1] Parkinson, Global Positioning System: Theory and Application, Vol.□□, AIAA, 1996

[2] Strang, G. and Borre, K., Linear Algebra, Geodesy,and GPS, Wellesley-Cambridge Press, 1997

[3] R.G. Brown and P.C. Hwang, Introduction toRandom Signals and Applied Kalman Filtering, Edition, John Wiley & Sons, Inc., 1992

[4] C. W. Jeon, H. J. Kim, “An LS-TLS Based Sequential Identification Algorithm: Application to an accelerometer”, IEEE Transactions on Aerospace and Electronics, Vol. 37, No. 2, pp. 607-618, 2001

[5] Chang Wan Jeon and Gérard Lachapelle, “A New TLS-Based Sequential Algorithm to Identify Two Failed Satellites”, International Journal of Control, Automation, and Systems, Vol. 3, No. 2, pp. 166-172, 2005